Effects of Sediment Microfabric on Benthic Optical Properties

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LONG-TERM GOALS

The long-term goal of this CoBOP project is to understand how natural inorganic variations in sediment microfabric (e.g., grain size, shape, sorting, composition, and orientation) effect the benthic light signal. Implicit within this is the development of quantitative relationships for those parameters that can be utilized in optical models and in the groundtruthing of optical remote sensing imagery.

OBJECTIVES

The objectives of this first field year (second year overall) of the CoBOP project were to obtain the first field measurements from two instrumentation tools developed in Year 1. The first is a microspectroradiometer which was used in this first field year to examine the fluorescence characteristics of inorganic sediment grains and what effect they may have on the benthic optical signal. The second instrument was a fiber-optic microprobe that was developed to measure the penetration of light at all visible and long-UV wavelengths into intact seabed samples. A series of experiments were designed to examine sediment microfabric using these instruments during the first year of CoBOP field studies at Lee Stocking Island, Bahamas and Monterey Bay, California. Two sites were designed to test the approach in a predominantly carbonate sediment setting and a siliciclastic setting.

Our initial studies in the laboratory of standard sediment mixtures obtained from the Monterey and Lee Stocking Island (LSI) sites focused our field plans toward testing the following hypotheses in this initial phase of fieldwork:

1) Microfabric of grains at the sediment surface and to a depth of light penetration (~1cm in well-sorted sands) has a strong impact on BDRF and the in-sediment light field. Sediment layering in the optically relevant zone (e.g., upper 1 cm) formed by changes in composition, size, shape, or packing are common in sandy marine sediments and are induced by temporal and spatial variations in benthic shear stress and sediment source.

2) Fluorescence of carbonate mineral grains is virtually universal in carbonate settings such as LSI and, therefore, has a significant effect on BDRF. Carbonate and other biogenic grains compose a smaller percentage of the Monterey sediment and have an inconsequential impact on the overall benthic light signal.

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3) Siliciclastic mineral fluorescence is present in 5-10% of the mineral grains at the Monterey site and is a useful tool for sediment provenance.

APPROACH

Sediment cores will be collected for testing the influence of microfabric from a variety of sediment and seagrass sites at LSI and Monterey Bay where BDRF and other light properties are measured. Cores will be returned to the laboratory for immediate (same day) measurement by the fiber-optic microprobe developed in Year 1 of scalar irradiance with depth. Following this, cores will be immediately impregnated by a process developed for this study that preserves the sediment fabric. Impregnated samples will then be thin-sectioned for examination of microfabric under a petrographic/epi-fluorescence microscope. We hypothesize that subbottom variations in layering in the optically relevant zone have an influence on BDRF and absorbance that decreases with increasing burial of the layer below the sediment surface. Fiber-optic measurements and impregnations will be carried out immediately, to reduce alteration, and on every thin-section sample. Image analysis software will be used to reduce grain-scale properties (e.g., porosity, grain size, shape) of each sample. An S4 electromagnetic current meter was deployed at the sites for the duration of the experiment to examine the relationship of observed microfabric with bed shear stress. It is anticipated that artificial layering-light properties experiments will be conducted in the laboratory to supplement the field observations.

Carbonate mineral fluorescence will be pursued by several avenues. A collaborative effort with D. Burdige (ODU) is underway to determine the source of fluorescence (e.g., uranium salts or organic compounds) in the mineral structure. Carbonate grains will be crushed to release internal matter, and treated for measurement on a Hitachi Fluoro-max of the inherent organic compounds. Our preliminary work on treated grains has shown this fluorescence is not an organic surface coating. The Hitachi spectrofluorometer of C. Mazel (PSI Corp.) will be used at LSI to determine the excitation-emission spectral signatures of various types of carbonate grains. Our initial work suggests that, unlike siliciclastic grains, excitation is not limited to the ultraviolet. The TAMU microspectroradiometer will be utilized to examine the distribution of various fluorescing components (e.g., are they organism or area specific). This equipment and other laboratory studies determine the overall impact of carbonate mineral fluorescence on BDRF and the in-sediment light field.

The spectral signatures of fluorescing siliciclastic minerals in Monterey Bay will be examined to determine how distribution of these mineral components is related to source. Source areas such as river inputs, fiber-optic sample sites, and a Bay-wide grid will be sampled to address provenance issues. Laboratory studies of optical response with the microspectroradiometer and fiber-optic system will be utilized to determine the overall impact of siliciclastic mineral fluorescence on BDRF and the in-sediment light field at Monterey.

WORK COMPLETED

Lee Stocking Island 98

During the first Lee Stocking Island CoBOP experiment, graduate student Brent Taylor and I completed the following field studies. Approximately 20 sediment cores were collected from a variety of sediment and seagrass sites at LSI in May where BRDF and other light properties were measured. Sites were established in league with the other members of the CoBOP sediment team to encompass a wide variety of biogeochemical conditions. Cores were returned to the laboratory at LSI and measured with the fiber-optic microprobe for scalar irradiance with depth. Measured samples were impregnated

immediately and are presently under analysis for their sedimentological and fabric character in thin-sections.

A suite of 30 carbonate-secreting organisms and fragments of larger organisms was collected of known provenance and taxonomy to examine the organism relationship with the carbonate fluorescence phenomenon (e.g., is it taxa-specific). These organisms represented a wide range of sediment producers including corals, calcareous green algae, echinoderms, molluscs, etc. Samples were returned to the laboratory and bleached to remove organic pigments to determine their "inorganic" fluorescence response. A number of these samples (~15) were examined using Charlie Mazel's Fluoromax probe attachment to determine the full excitation-emission characteristics of the carbonate fluorescence using powdered samples (Figure 1). The remaining samples are being examined at TAMU for emission spectra with our microspectroradiometer. Loose surface sediment samples were collected from a wide range of areas around LSI including beaches, ooid shoals, reef sands, etc. to examine the fluorescence characteristics of sediment grains that result from the organism-producers studied. This sampling was directed to determine if the fluorescene is site or environment specific. Work is underway at TAMU to look at the grain-specific fluorescence of these samples to determine if sediment provenance is as important to the fluorescence as is the source organism; i.e., is a reef coral in the offshore similar to one secreting carbonate in lagoonal water, for instance?

Monterey Bay

Three samples for fiber-optic measurements and thin-section examination were collected and processed in April 1998. As this was the first field test of the system prior to deployment at LSI98, most of the effort was directed at refining techniques. A second field experiment was done in October 1998 following the CoBOP workshop. Seven cores were collected from three sites sampled by a subset of the LSI sediment team (Zimmerman, Dobbs, Burdige) for various parameters. Measurements of scalar irradiance were made for all the samples and analysis of the data, and resulting thin-sections is underway. A suite of loose sediment samples was also collected on the beaches surrounding Monterey Bay to examine the fluorescence characteristics of sediments arriving in the bay from different provenances. In a future field study, a sampling grid is planned for the Bay itself to examine whether siliciclastic mineral fluorescence is a useful provenance tool for sand grains.

RESULTS

Results from the fiber-optic microprobe analyses to date (Fig. 1) suggest a wide variation in penetration of scalar irradiance that is controlled by a combination of grain characteristics (mainly size and sorting) and geochemical parameters (precipitation of sulfides in the reducing zone, for instance). Light penetration of >0.1% incident is confined to the upper few millimeters in carbonate and siliciclastic environments; LSI sediments overall show a greater penetration than Monterey likely due to the better sorting (fewer fines) and higher albedo of the grains (carbonates are white). Penetration increases with increasing wavelength, suggesting infrared light might make a useful tool for examining microfabric on centimeter length scales. Samples often show a greater than 100% incident zone immediately above the sediment-water interface that is hypothesized to be caused by increased scattering. This zone varies in intensity between samples likely due to size and albedo of sediment surface grains. In sediments with well-developed mats and biofilms, the biological component exerts a strong influence on the spectral signal, causing absorption at wavelengths corresponding to important biopigments (chlorophyll, etc.). Measurements were made on Monterey cores in October 1998 with a narrow bandwidth (455, 488, 515, and 640 nm) filtered light source to produce fluorescence “maps” in

the subsurface of the relative abundance, distribution, and overall impact on the light signal of these biopigments.

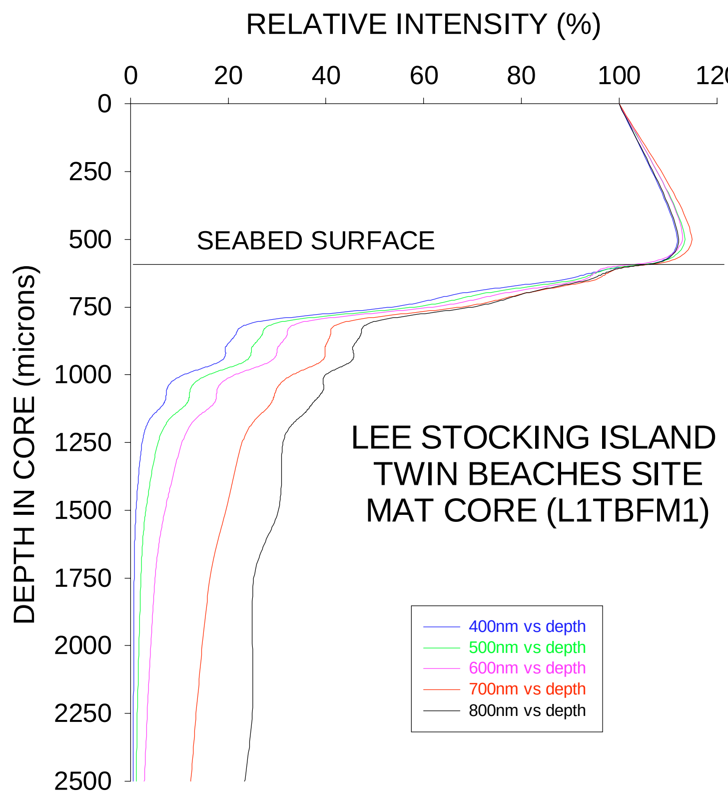

Figure 1. Fiber-optic microprobe measurement of the in-sediment light field of relative spectral irradiance from an algal mat at Lee Stocking Island in May 1998. Note the scattering boundary layer immediately above the sediment surface where values exceed those higher in the water column. Decreased light penetration at short wavelengths is probably a result of increased scattering in the dense sediment medium. Full spectral plots exhibit strong 670 nm chlorophyll absorbance at certain layers (benthic diatom zones?).

Initial results from the inorganic carbonate fluorescence (Fig. 2) suggest that there is a wide-band, weak (relative to live corals) fluorescence in almost all samples although exact wavelengths are variable. A few organisms (e.g., echinoderms) have a significantly different and weaker signal than other varieties. This fluorescence, judging from the sediment test with the laser line scanner system during the field campaign, is a major contributor to the green background glow seen in FILLS images. Initial results from the studies of grain provenance (e.g., is fluorescence site-specific) show a small percentage of grains have a dramatically different fluorescence signatures (e.g., blue, orange) than the average wide-band carbonate signal. It is unclear at this point if this results from organic (internal) or inorganic sources.

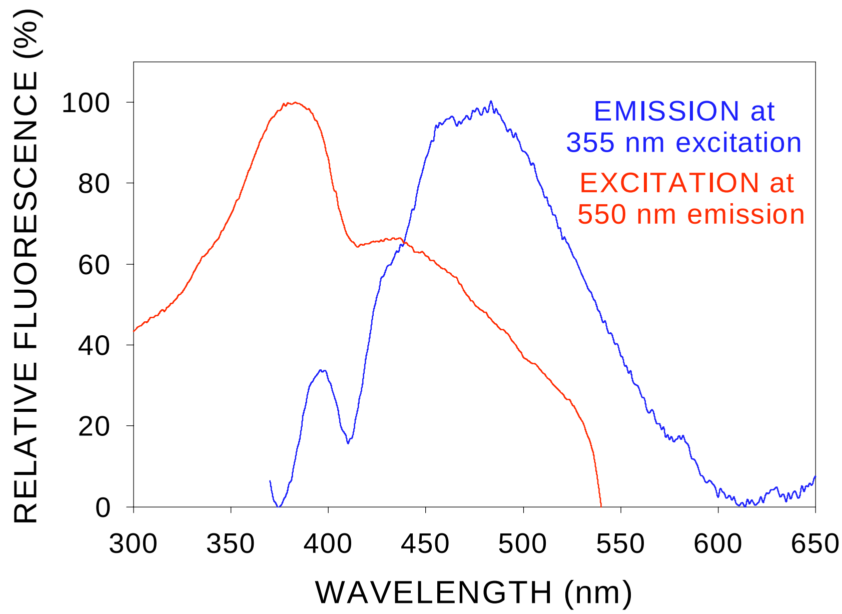

Figure 2. Excitation and emission fluorescence profiles for Halimeda incrassata grains treated to remove the surface organic signal. Halimeda is a calcareous algae that is a major sediment source to carbonate platform areas. The broad fluorescence emission is attributed to the carbonate mineral fluorescence. This broad fluorescence is thought to be responsible for the background green fluorescence of laser-line scan images from Lee Stocking Island.

IMPACT/APPLICATIONS

The fiber-optic microprobe studies are the first ever conducted on undisturbed, marine sediments. Previous studies had focused on sediment manipulation experiments. These experiments are the first information on the in-sediment light field from real coastal settings. This is the first crucial step for developing an in-situ microprobe that can utilize the solar light field as the incident light source. The fluorescence studies hold promise for correcting remote instrumentation (e.g., laser line scanner) for use in carbonate seafloor settings. Siliciclastic mineral fluorescence potentially will become a useful sedimentological tool for examining grain provenance, as it is not only mineral specific, but also specific to the mineral of a specific source local. This holds promise of supplementing other techniques, like heavy mineral analysis, for tracking sand transport vectors from a source area.

TRANSITIONS

All data from this project is being submitted to the CoBOP database under construction to allow utilization by other CoBOP scientists. Data is not yet being utilized in the greater oceanographic community as the publication of results will not begin until 1999.

RELATED PROJECTS

The present study is closely related to other CoBOP projects in terms of scientific goals, field areas, and development of optical seabed models. The closest ongoing collaborations are with other members of the CoBOP “sediment” subgroup of investigators.